TITLE OF INVENTION

Cross-Calibration of Plant Instruments with Computer Data

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] Not Applicable

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] Not Applicable

BACKGROUND OF THE INVENTION

1. Field of Invention

[0003] This invention pertains to methods and apparatus for performing RTD and thermocouple cross-calibration in nuclear power plants. More particularly, this invention pertains to using data acquired by a plant monitoring system to calibrate hot leg and cold leg temperature instrumentation in a pressurized water reactor.

2. Description of the Related Art

[0004] Pressurized water reactors (PWRs) produce heat through a nuclear reaction in a reactor vessel. The heat is extracted from the reactor vessel by pumping water from the reactor vessel to one or more steam generators. The steam generator is a heat exchanger that extracts the heat from the reactor water into steam that drives a turbine. The piping carrying the heated water from the reactor vessel is called the hot leg, and the piping carrying the cooled water back into the reactor vessel is called the cold leg.

[0005] In order to maintain control of the reactor system, the temperature of the reactor water in the hot leg and the cold leg is monitored during reactor start up, shut down, and normal operation. It is common practice to use redundant resistance temperature devices (RTDs) in this application.

[0006] Additionally, the temperature of the heated water as it leaves the reactor core is measured by core-exit thermocouples (CETs). A core-exit thermocouple system allows the continuous, on-line monitoring of the coolant temperature at the exit of about one fourth of the fuel assemblies. In present practice, these core-exit thermocouples are installed at or just above the outlet nozzles of a fraction of the fuel assemblies in most commercial pressurized water nuclear power reactors. Typical reactor cores generally consist of from approximately one hundred to more than two hundred fuel assemblies and the core-exit thermocouples are usually located at approximately one out of four fuel assemblies.

[0007] Typically, an on-line plant process control computer periodically samples the hot and cold leg RTD resistance and the core-exit thermocouple voltages. These values are converted to convenient engineering units, for example, degrees Fahrenheit or degrees Celsius.

[0008] The temperatures measured by the RTDs and CETs are used by the plant operators for process control and to assess the safety of the plant as well as the overall efficiency of power generation. Because the measurements of the RTDs and CETs play a critical role in the evaluation of the plant's operating status, the calibration of the RTDs and CETs are normally evaluated at least once every refueling cycle. Because of plant operating constraints, calibration typically occurs during plant shutdown periods, such as when the reactor core is being refueled, which can occur on an 18-month cycle. Each RTD and CET instrument must meet specific requirements for the plant to continue to produce power according to its design specifications.

[0009] In a typical nuclear power plant design, redundant RTDs and CETs are placed in the plant's fluid loops to minimize the probability of failure of any one RTD or CET having a serious effect on the operator's ability to safely and efficiently operate the plant. This redundancy of temperature measurements is the basis for a method of evaluating the calibration of RTDs and CETs called 'cross calibration'. In cross calibration, redundant temperature measurements are averaged to produce an estimate of the true process temperature. The measurements of each

individual RTD and CET are then compared with the process estimate. If the deviations from the process estimate of an RTD or CET is within acceptable limits, the sensor is considered in calibration. However, if the deviation exceeds the acceptance limits, the sensor is considered out of calibration and its use for plant operation must be evaluated.

[0010] Figure 1 illustrates two prior art methods of performing cross calibrations, along with a third method in accordance with the present invention. The plant process **102** is monitored by plant instruments **104**, such as RTDs and CETs. The first prior art method of performing cross calibrations is to collect manual measurements **106** of the instruments, and then perform manual calculations **108** to produce the cross calibration results **110**. A second prior art method of performing cross calibrations is to use a dedicated data acquisition system **112** to collect the data and produce the results **114**. The typical process for performing the cross-calibration occurs when the plant is shutting down for a refueling outage or starting up after an outage when the fluid temperatures go through ranges allowing measurements over the sensor range. The procedure for obtaining the sensor measurements involves physically disconnecting the RTDs or CETs from the plant indications and making measurements using a multimeter or dedicated data acquisition systems. The measurement data is then presented to the plant engineers and used to assess the sensor calibrations with the help of software or manual calculations. After the cross calibration analysis is performed the sensors are connected to the instrumentation to provide indication to the operators.

[0011] These prior art methods have the disadvantage of removing the instruments from service for the period measurements are taken, resulting in less information being provided to the plant operators. Additionally, the prior art methods require time and manpower to perform the cross calibrations. Attaching the equipment for the manual measurements **106** or the dedicated data acquisition system **112** requires a trained technician to make the connections and take the actual measurements.

BRIEF SUMMARY OF THE INVENTION

[0012] According to one embodiment of the present invention, an automated system for cross calibration is provided. Information and data is extracted from a plant computer or on-line monitoring system. This information and data is processed to perform a cross calibration check of the instruments. The processing of the information and data is performed by a computer system running software.

[0013] In one embodiment, the software includes routines to load a data set from the plant monitoring system, to select a set of data to analyze, to remove deviating data, to analyze the remaining data, and to recalibrate any deviating instruments. In another embodiment, the software includes routines to retrieve data from the plant monitoring system, to perform averaging calculations, to identify outliers, and to calculate new calibration curves for the outliers.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0014] The above-mentioned features of the invention will become more clearly understood from the following detailed description of the invention read together with the drawings in which:

Figure 1 is a block diagram of one embodiment of the present invention integrated into a plant monitoring system;

Figure 2 is a piping and instrumentation diagram of a reactor loop with temperature instruments;

Figure 3 is a block diagram of one embodiment of the present invention;

Figure 4 is a block diagram of one embodiment of the software for the present invention;

Figure 5 is a block diagram of one embodiment of the load data routine;

Figure 6 is a block diagram of one embodiment of the file selection routine;

Figure 7 is a block diagram of one embodiment of the load RTD data routine;

Figure 8 is a block diagram of one embodiment of the calculate RTD averages routine;

Figure 9 is a block diagram of one embodiment of the calculate averages routine;

Figure 10 is a block diagram of one embodiment of the load CET data routine;

Figure 11 is a block diagram of one embodiment of the calculate CET averages routine;

Figure 12 is a block diagram of one embodiment of the select routine;

Figure 13 is a block diagram of one embodiment of the calculate three narrow range regions routine;

Figure 14 is a block diagram of one embodiment of the separate RTD data into regions routine;

Figure 15 is a block diagram of one embodiment of the fluctuation removal routine;

Figure 16 is a block diagram of one embodiment of the analyze routine;

Figure 17 is a block diagram of one embodiment of the calculate deviations in narrow range regions routine;

Figure 18 is a block diagram of one embodiment of the calculate deviations in wide range regions routine;

Figure 19 is a block diagram of one embodiment of the calculate average deviation and standard deviation for each RTD routine;

Figure 20 is a block diagram of one embodiment of the calculate CET deviations routine;

Figure 21 is a block diagram of one embodiment of the calculate average deviation for each CET routine;

Figure 22 is a block diagram of one embodiment of the RTD report routine;

Figure 23 is a block diagram of one embodiment of the calculate percent removed for narrow range regions routine;

Figure 24 is a block diagram of one embodiment of the calculate percent removed for wide range region routine;

Figure 25 is a block diagram of one embodiment of the calculate the mean value of the averages routine;

Figure 26 is a block diagram of one embodiment of the CET report routine;

Figure 27 is a block diagram of one embodiment of the calculate CET quadrant averages for each region routine;

Figure 28 is a block diagram of one embodiment of the recalibrate for selected recalibration RTD routine;

Figure 29 is a block diagram of one embodiment of the calculate resistance versus temperature table for selected RTD routine;

Figure 30 is a block diagram of one embodiment of the calculate new coefficient routine;

Figure 31 is a block diagram of one embodiment of the calculate quadratic coefficient routine;

Figure 32 is a block diagram of one embodiment of the calculate Callendar coefficient routine;

Figure 33 is a block diagram of one embodiment of the calculate quadratic linear coefficient routine;

Figure 34 is a block diagram of one embodiment of the calculate Callendar linear coefficient routine;

Figure 35 is a block diagram of one embodiment of the calculate reference coefficient routine;

Figure 36 is a block diagram of one embodiment of the produce recalibration-original plot routine;

Figure 37 is a block diagram of one embodiment of the recalibration uncertainty calculation routine;

Figure 38 illustrates an example screen shot of an RTD calibration plot;

Figure 39 illustrates an example screen shot of an RTD calibration uncertainty plot; and

Figure 40 illustrates an example screen shot of an RTD calibration table.

DETAILED DESCRIPTION OF THE INVENTION

[0015] Methods and apparatus for an automated system for cross calibration are disclosed. The invention will be described as applied to a pressurized water reactor (PWR) for generating electric power. The invention, however, is applicable to other processes in which a multitude of sensors monitor a process.

[0016] Figure 1 illustrates a block diagram of both the prior art methods and the present invention. The plant process **102** is monitored by plant instruments **104**, such as RTDs and CETs. As described above, cross calibration can be performed either by manually measuring **106** the instruments **104** and then performing manual calculations **108** to obtain the results **110** or by using a dedicated data acquisition system **112** to collect and analyze the data and produce the results **114**.

[0017] In a typical plant environment, the plant instruments **104** provide data to a centralized plant computer **122** that monitors the instruments **104** and

stores the instrument measurements in a data storage unit **124**. The plant computer **122** performs data acquisition for the plant, collecting process information from various instruments. In the present invention, a cross calibration processor **126** interrogates, or communicates with, the data storage unit **124** of the plant computer **122** and processes the instrument data to produce the cross calibration results **128**. The data storage unit **124**, in one embodiment, is a standalone storage unit with its own processor. In another embodiment, the data storage unit **124** is a disk farm or array for storing data processed by the plant computer **122**.

[0018] In the past, the plant data acquisition system (plant computer **122** and data storage **124**) has been a prohibitive factor in the storing of plant computer data at sampling rates sufficient for cross calibration analysis. However, recent advances in technologies for monitoring and storing large amounts of data and their adoption in nuclear plant information systems have made it possible to acquire and store data at adequate sampling rates for performing cross-calibration without the need for dedicated data acquisition equipment. For example, only recently have equipment become available that makes it practical to monitor an instrument at one second intervals.

[0019] The database maintained by the plant computer **122** is interrogated to provide the necessary data to perform cross calibration analysis of RTDs and CETs. More specifically, the system involves software and a computer or other equipment to extract and analyze data from the database to verify the calibration of various temperature sensors. The system uses data from all temperature regions to verify the performance of the instruments over their entire operating range. For example, temperature data is collected from redundant temperature sensors during plant start-up (heatup) or shut down (cool down) at temperature ramp conditions to verify the calibration of temperature sensors over a wide range and to help develop new calibration curves for a sensor that fails the test. The latter amounts to in-situ recalibration of the sensor. This recalibration provides an option to perform a linear correction between the original calibration curve and the new calibration data that is necessary when recalibrating a narrow range RTD over its temperature region.

[0020] The temperature region is a portion of the temperature range in which multiple instruments provide measurements. For example, during plant startup, the temperature of the primary loops slowly increases with the wide range temperature instruments reading the temperature over the full range and the narrow range instruments reading the temperature as the temperature approaches the operation temperature. For a particular temperature range to be used for cross-calibration, in one embodiment, three regions are defined. Roughly, these three regions correspond to a smaller range within the lower, mid, and upper portion of the temperature range.

[0021] As used herein, the cross calibration processor **126** should be broadly construed to mean any computer or component thereof that executes software. The processor **126** includes a memory medium that stores software, a processing unit that executes the software, and input/output (I/O) units for communicating with external devices. Those skilled in the art will recognize that the memory medium associated with the processor **126** can be either internal or external to the processing unit of the processor without departing from the scope and spirit of the present invention. Further, in one embodiment, the processor **126** communicates with the plant computer **122** and/or the data storage unit **124** via a network connection.

[0022] The processor **126** should be broadly construed to mean any computer or component thereof that executes software. In one embodiment the processor **126** is a general purpose computer, in another embodiment, it is a specialized device for implementing the functions of the invention. Those skilled in the art will recognize that the processor **126** includes an input component, an output component, a storage component, and a processing component. The input component receives input from external devices, such as the plant computer **122** or the data storage unit **124** attached to the plant computer **122**. The output component sends output to external devices, such as a printer, the plant computer **122**, or another computer system or network. The storage component stores data and program code. In one embodiment, the storage component includes random access memory. In another embodiment, the storage component includes non-volatile memory, such as floppy disks, hard disks, and writeable optical disks. The

processing component executes the instructions included in the software and routines.

[0023] Figure 2 illustrates a single loop of a reactor coolant system for a pressurized water reactor (PWR). The reactor (Rx) vessel **202** contains the nuclear core, which heats the water. The heated water exits the hot leg piping **212**, which is routed to the steam generator (SG) **204**, where the heat generated in the reactor vessel **202** is converted to steam for driving a turbine. The cooled water exits the steam generator **204** to a reactor coolant pump **206**, which pumps the water through the cold leg piping **214** into the reactor vessel **202**. The vessel **202** illustrated in Figure 2 only shows, for clarity, one steam generator **204** in a closed fluid system or loop, however, it should be understood that the number of such loops and steam generators **204** varies from plant to plant and commonly two, three, or four are employed. Also shown in Figure 1 is a pressurizer (P) **208**, which serves to maintain the pressure in the reactor coolant system. The pressurizer **208** is typically found on only one loop of the reactor coolant system.

[0024] The hot and cold legs **212**, **214** include temperature monitoring instruments (T) **222**, **224**, **232**, **234**, which are resistance temperature detectors (RTDs). Resistance temperature detectors are devices in which their resistance varies in relation to their temperature. Various means for analytically determining temperature from resistance of RTDs are known. One method is the quadratic equation:

[0025] $R_T = R_0 \bullet \{1 + A \bullet T + B \bullet T^2\}$

where: R_T =Resistance (ohms) at Temperature T (degrees Celsius (C))

R_0 = Sensor-specific constant (Resistance at t=0 degrees C)

A = Sensor-specific constant

B = Sensor-specific constant

[0026] The quadratic equation is an approximation that is accurate over a certain temperature range. Another method of modeling an RTD is the Callendar equation:

[0027] $R_T = R_0 \bullet \{1 + \alpha\,(1 + 0.01 \bullet \delta)\,T - \alpha \bullet \delta / 10^4 \bullet T^2\}$ (for $T \geq 0$ degree C)

where: R_T =Resistance (ohms) at Temperature T (degrees Celsius)

R_0 =Sensor-specific constant (Resistance at t=0 degrees C)

α (alpha) = Sensor-specific constant

δ (delta) = Sensor-specific constant

[0028] The Callendar equation is an approximation that is accurate above zero degrees Celsius. Still another method of modeling an RTD is the Westinghouse Reference equation:

[0029] $R_T = \mathrm{Ref}(T) + \mathrm{Offset} - \mathrm{Slope} \bullet (T - 525)$

where: $\mathrm{Ref}(T) = R = 185.807 + 0.444693T - 0.000036082T^2$ degrees Fahrenheit

Offset = sensor specific constant

Slope = sensor specific constant

[0030] The Westinghouse Reference function applies a linear adjustment to a standard quadratic reference. This is used in some plant instrumentation to simplify the conversion between resistance and temperature.

[0031] The Callendar and quadratic equations are equivalent when performing a second order fit. The Westinghouse Reference is constrained in how well it can fit a specific RTD due to its reference function. The quadratic linear and Callendar linear produce the second order equations, but are generated with a linear (first order) fit to the difference between the calibration data and the previous calibration.

[0032] The exact values of the coefficients (R_0, α, δ, and β), (R_0, A, and B), and (offset and slope) are specific to each RTD device and are obtained by testing each individual sensor at various temperatures.

[0033] The hot leg **212** includes at least one wide range temperature sensor **222** that is calibrated to measure the temperature of the reactor coolant in the hot leg **212** from startup to operating to shutdown. The hot leg **212** also includes at least one narrow range temperature sensor **224** that is calibrated to measure the

temperature of the reactor coolant in the hot leg **212** under operating conditions. The narrow range temperature sensor **224** is used to control and monitor the reactor during operation, accordingly, it is common to have redundant sensors **224** for each hot leg **212**. It is known to have up to three dual element RTDs for each hot leg **212**. For example, three of the RTD elements are in service with three elements in reserve as spares.

[0034] The cold leg **214** includes at least one wide range temperature sensor **232** that is calibrated to measure the temperature of the reactor coolant in the cold leg **214** from startup to operating to shutdown. The cold leg **214** also includes at least one narrow range temperature sensor **234** that is calibrated to measure the temperature of the reactor coolant in the cold leg **214** under operating conditions. As with the hot leg **212** narrow range sensors **224**, there are redundant cold leg **214** narrow range sensors **234**. It is known to have two narrow range sensors **234** for each cold leg **214**.

[0035] Core-exit thermocouples (CETs) **242** are inside the reactor vessel **202** and above selected fuel bundles. The CETs **242** are grouped into quadrants, that is, quarter-sections of the circular cross-section of the reactor core. Thermocouples are based on the effect that the junction between two different metals produces a voltage which increases with temperature. Thermocouples typically have a measurement junction and a reference junction, and they measure the temperature difference between the two junctions.

[0036] The hot leg temperature sensors **222**, **224**, the cold leg temperature sensors **232**, **234**, and the core-exit thermocouples **242** communicate with the plant monitoring system **240**. The plant monitoring system **240** provides indication and data acquisition of instrumentation, thereby monitoring the condition of plant processes. The plant monitoring system **240** includes the plant computer **122** and the data storage unit **124**, in addition to other associated equipment, such as isolators. In the embodiment illustrated in Figure 2, the cross calibration processor **126** is in communication with the plant monitoring system **240**. In one embodiment, the processor **126** communicates with the plant monitoring system **240** via a network connection.

[0037] In a typical reactor coolant system, the temperatures measured by each of the sensors **222**, **224**, **232**, **234**, **242** fall within a narrow range at any point in time. For example, the hot leg **212** temperature during operation should be slightly hotter than the temperature of the cold leg **214**. The difference in temperature is related to the temperature drop across the steam generator **204**. At some plants, this temperature variation may be approximately 50 degrees Celsius with the cold leg temperature being approximately 550 degrees Celsius. Further, the temperature measured by the redundant instruments **222**, **224**, **232**, **234**, **242** typically fall within an even narrower range.

[0038] In one embodiment, the temperature data collected by the plant computer **122** includes process data produced during isothermal conditions. That is, in a pressurized nuclear plant, the primary coolant system is brought up to temperature by the heating produced by the reactor coolant pumps **206** without relying upon the reactor to produce heat. In isothermal conditions, the temperature varies throughout the system only from heat loss from the system components, and this variation is less than the temperature variation throughout the system with the reactor in operation. In this embodiment, under isothermal conditions, the hot leg temperature sensors **222**, **224**, the cold leg temperature sensors **232**, **234**, and the core-exit thermocouples **242** all measure the reactor coolant fluid temperature with similar or related readings. In another embodiment, the data collected by the plant computer **122** includes process data produced during plant conditions in which the instruments **104** being cross-calibrated are operating under equilibrium, that is, the subject instruments **104** are responding to a measured parameter that is substantially identical or related for all instruments **104**.

[0039] In another embodiment, the process variable being measured is not temperature, but some other process variable, for example, pressure or radiation. In still another embodiment, the instruments **104** are not necessarily redundant instruments, but are instruments **104** that produce similar or related readings under controlled conditions.

[0040] Figure 3 illustrates a simplified block diagram of one embodiment of the present invention. The first step is to retrieve data **302** from the plant monitoring system **240**. Once retrieved, the data is sorted **304** to allow for easier processing. The next step is to determine the average temperatures **306** of the various temperature instruments. After the average temperatures are known, the next step is to determine the deviations **308** of each of the instruments from the averages. For deviations outside a range **310**, the next step is to determine new coefficients, or calibration curves, **312**. For those instruments with no deviations outside the range, there is no change **314**.

[0041] Figure 4 illustrates a block diagram of another embodiment of the software executed by the cross calibration processor **126**. Each software function identified is further broken down in another figure, providing a greater and greater level of detail for the various functions performed by the cross calibration processor **126**.

[0042] The first function illustrated in Figure 4 is to load, or retrieve, the data **402**. Figure 5 illustrates a detailed block diagram of the functional steps for loading the data **402**. After the data is loaded **402**, the next step is to select the data points **404**. Figure 12 illustrates a block diagram of the functional steps for selecting the data points **404**. After the data points are selected **404**, the next step is fluctuation removal, or to remove deviate data, **406**. Figure 15 illustrates a block diagram of the functional steps for removing deviate data **406**. After the deviate data is removed **406**, the next step is to analyze the data **408**. Figure 16 illustrates a block diagram of the functional steps for analyzing the data **408**. After the analysis **408**, the next step is the RTD report **410** and the CET report **412**. Figure 22 illustrates a block diagram of the functional steps for generating the RTD report **410**. Figure 26 illustrates a block diagram of the functional steps for generating the CET report **412**. The final step is to recalibrate any deviating or outlying RTDs **414**. Figure 28 illustrates a block diagram of the functional steps for recalibrating any deviating RTDs **414**. As used in herein, a report includes providing data to a user, whether printed or displayed, whether in visual format or digital format.

[0043] The software executed by the cross calibration processor **126** includes user interface routines and configuration setup routines. The configuration routines include storing values for the maximum and minimum temperature range settings for acceptable process estimates from the RTDs; the size in temperature of the partitions used to calculate deviations, the deviation limits between RTDs and CETs used in rejecting measurements from the average, the Standard Deviation limit multiplier used in process fluctuation removal, and the information regarding the sensors used in the software. Sensor information includes sensor name, narrow or wide range designation, hot or cold loop designation, use in the average, coefficients for conversion from resistance or voltage to temperature, uncertainty values for each sensor, core location, quadrant, and other data. The configuration values identified above are used in the various routines described below. The user interface routing, in various embodiments, allows the operator to load, save, print, and/or modify the configuration settings.

[0044] The following table illustrates the configuration values stored for one embodiment::

Software Variables:

NR Min	Narrow Range minimum value
NR Max	Narrow Range maximum value
NR Region Size	Narrow Range size in temperature of the partition to calculate deviations
WR Min	Wide Range minimum value
WR Max	Wide Range maximum value
WR Region Size	Wide Range size in temperature of the partition to calculate deviations
SDEV Limit	Standard Deviation limit multiplier

Sensor Information:

Sensor ID	Name or identifier of sensor
Sensor Type	Type of sensor, e.g., RTD or CET
Sensor designation	Narrow or wide range, cold or hot leg
Sensor Conversion Factor	Conversion factor to convert sensor info to process units
Sensor Uncertainty	Uncertainty value for the particular sensor

[0045] The user interface, in various embodiments, includes a load and select screen associated with loading the data **402** and selecting the data points **404**, an RTD fluctuation removal screen associated with fluctuation removal **406**, an analysis screen associated with analyzing the data **408**, an RTD report screen associated with the RTD report **410**, a CET report screen associated with the CET report **412**, an RTD recalibration screen associated with recalibrating any deviating RTDs **414**, and/or an RTD recalibration uncertainty screen associated with recalibrating any deviating RTDs **414**.

[0046] The load and select screen associated with loading the data **402** and selecting the data points **404** allows for loading data from multiple files with RTD and/or CET data or directly from the plant computer database. It also allows for displaying and printing all average types from the loaded data. Further, it allows for selecting the data to be analyzed by bounding the desired data with graph cursors and separating the data into regions based on the maximum and minimum temperature range settings from the configuration data. The load and select screen allows for displaying and printing the deviations of each average type for all of the loaded data or for data separated into regions.

[0047] The RTD fluctuation removal screen associated with fluctuation removal **406**, in various embodiments, allows for displaying and printing the standard deviation of the process estimate average with and without the standard deviation fluctuation removed for each region of the data. The screen also allows

for displaying and printing information including the initial number of samples, final number of samples after standard deviation fluctuation removal, percent of initial data used, standard deviation multiplier, average standard deviation, standard deviation of the average standard deviation, high fluctuation removal limit, low fluctuation removal limit.

[0048] The analysis screen associated with analyzing the data **408**, in various embodiments, allows for displaying and printing, for a selected region, each average type and the deviations from the process estimate for all RTDs and CETs. The analysis screen also allows for displaying and printing, for a selected narrow range region, the deviations from the process average with corrections applied. Also, the screen allows for displaying and printing deviations by sensor group or individually by tag or ID number.

[0049] The RTD report screen associated with the RTD report **410**, in various embodiments, allows for displaying, loading, saving, and printing RTD cross calibration results information for each region and correction type. The screen also allows the option to save all RTD cross calibration results as a text file.

[0050] The CET report screen associated with the CET report **412**, in various embodiments, allows for displaying, loading, saving, and printing cross calibration results information for each region and average type. The screen also allows the option to save all RTD cross calibration results as a text file.

[0051] The RTD recalibration screen associated with recalibrating any deviating RTDs **414**, in various embodiments, allows for displaying and printing recalibration information for the selected RTD and calibration type. Calibration types include Callendar, Callendar Linear, Westinghouse Reference, Quadratic, and Quadratic Linear. Recalibration information includes temperature per region, measured average resistance per region, RSS uncertainties per region, original calibration constants/coefficients, and new calibration constants/coefficients. The recalibration screen allows for displaying and printing a graph of new calibration points – original calibration points vs. temperature and a calibration

table for a selected RTD. The screen also allows the option to save calibration information to a text file.

[0052] The RTD recalibration uncertainty screen associated with recalibrating any deviating RTDs **414**, in various embodiments, allows for displaying and printing the uncertainty curves for the new calibration points.

[0053] Figure 5 illustrates a detailed block diagram of one embodiment of the functional steps for loading the data **402**. In the illustrated embodiment, the first step is to select the file **502**. Figure 6 illustrates a detailed block diagram of the functional steps for selecting the file **502**. The next step after selecting the file **502** is to load the RTD data **504**. Figure 7 illustrates a detailed block diagram of the functional steps for loading the RTD data **504**. The next step after loading the RTD data **504** is to calculate the RTD averages **506**. Figure 8 illustrates a detailed block diagram of the functional steps for calculating the RTD averages **506** for each timeslice. Figure 9 illustrates a detailed block diagram of the functional steps for the routine for calculating each average as shown on Figure 8. The next step after calculating the RTD averages **506** is to load the CET data **508**. Figure 10 illustrates a detailed block diagram of the functional steps for loading the CET data **508**. The next step after loading the CET data **508** is to calculate the CET averages **510**. Figure 11 illustrates a detailed block diagram of the functional steps for calculating the CET averages **510**. The next step after calculating the CET averages **510** is to match the timeslices **512** for the RTD and CET data. Some plants store the CET data at a slower rate than the RTD data, i.e. CET 10 seconds and RTD 1 second. In order to compare the CET data with the RTD data, the timeslices (samples) that have the same sample time for the RTD and CET data are selected (matched). The unmatched data is not used for the CET and RTD comparison. In a broad sense, a timeslice is a time period in which the data samples are considered to be taken practically simultaneous.

[0054] In another embodiment, the step of loading the data **402** includes an option for manually entering instrument data. For example, instead of selecting the file **502**, loading the RTD data **504** and/or loading the CET data **508**, an input screen is provided for the operator to manually input data for specific instruments.

Thus, instrument data for a temperature range not recorded by the plant computer **122** can be used for the cross calibration. In still another embodiment, the step for selecting the file **502** includes reading a file containing data from a source other than the plant computer **122**.

[0055] Figure 6 illustrates a detailed block diagram of one embodiment of the functional steps for selecting the file **502**. The first step is to display the files **602**, which, in one embodiment, includes displaying a list of the files in a selected location relating to a specific instrument. Each file includes data relating to information such as sensor names, units, description, date and time of each sample, and sensor measurements. The next step, displaying time and date information **604**, includes displaying the first and last date and time for the data in each file. The next step, display temperatures **606**, includes displaying the temperature range of the data in each file. The next step, determine and display type **608**, includes determining whether the data in each file is from an RTD, CET, or both, and then displaying that information. In one embodiment, the above steps **602**, **604**, **606**, **608** occur in any order to display multiple pieces of information relating to each file. In another embodiment, only one of the above steps **602**, **604**, **606**, **608** occur, with the operator selecting which information to display on a console screen.

[0056] After the information is displayed, the next steps allow for sorting by date **610**, which includes sorting the previously displayed data in order by date, or sorting by type **612**, which includes sorting the previously displayed data in order by the previously determined type **608**. After the data is presented to the operator, the operator selects one or more files **614** containing the data to be processed.

[0057] In the illustrated embodiment, the operator is presented with information with which the operator can make the decision as to which data is to be used for processing. In other embodiments, the operator is presented with information that results in the proper files being selected for processing. In various embodiments, this information includes one or more of the information displayed in steps **602**, **604**, **606**, **608** and/or includes other information.

[0058] Figure 7 illustrates a detailed block diagram of one embodiment of the functional steps for loading the RTD data **504**. The first step is to read the RTD data **702** from the RTD file. The second step, remove timeslice **704**, includes removing any timeslice data if the any of the data in the timeslice is not numeric or is less than some specified value. In one embodiment, the specified value is 0.1. After any suspect data is removed **704**, the next step is to convert the data **706**. In one embodiment, the data is converted from an instrumentation value to a process value. For example, a voltage reading from a transmitter is converted to the process temperature value, such as degrees Celsius. After any conversion **706**, the next step is to determine if all files have been read **708**. If not, the routine cycles back to the step of reading the RTD data **702**. If all the data files have been read **708** and processed, the routine exits to the next step of calculating the RTD averages **506**.

[0059] Figure 8 illustrates a detailed block diagram of one embodiment of the functional steps for calculating the RTD averages **506** for each timeslice. Figure 8 illustrates the various steps for calculating the RTD averages **506** as sequential steps. In other embodiments, the steps are performed in different sequences or simultaneously.

[0060] The first illustrated step, calculate wide range (WR) average **802** is associated with the step of calculating RSS uncertainty **822** for the WR RTDs. The step of calculating the RSS uncertainty **822** includes calculating the uncertainty using a root sum square (RSS) methodology. Calculating the RTD averages **506** further includes calculating the WR hot and cold leg averages **804**, calculating the WR loop average **806**, calculating the WR hot and cold loop average **808**, calculating the narrow range (NR) average **810**, calculating the NR hot and cold leg average **812**, calculating the NR loop average **814**, and calculating the NR hot and cold loop average **816**. Associated with calculating the NR average **810** is calculating the RSS uncertainty **830** for the NR RTDs.

[0061] Since the measurement uncertainties are provided for each sensor, the uncertainty for each average temperature is calculated as: $\mu_t = \frac{\sqrt{\Sigma \mu_i^2}}{n}$

μ_i = each sensor measurement's uncertainty

n = number of sensors in the average

μ_t= average temperature uncertainty for one sample

[0062] Figure 9 illustrates a detailed block diagram of one embodiment of the functional steps for the routine for calculating each average for the steps **802**, **804**, **806**, **808**, **810**, **812**, **814**, **816** shown on Figure 8. For each step **802**, **804**, **806**, **808**, **810**, **812**, **814**, **816**, the timeslice average of all process values for the associated RTDs is calculated **902**. The next step is to calculate the deviations **904**, which includes calculating the deviation from the average for each RTD used in the average calculation. The next step is to evaluate the deviations to determine if all the RTDs are to be used **906**. This evaluation includes examining each deviation determined in step **904** and if any RTD has a deviation that is not above a specified low criteria and below a specified high criteria, that RTD is removed as an outlier **908** and the timeslice average is calculated **902** again without considering that RTD. If after calculating the deviations **904**, all the RTD deviations fall within limits, the next step is to calculate the sample standard deviation (SD) **910**. The standard deviation for all the RTDs used to calculate the average **902** is determined for each timeslice.

[0063] Figure 10 illustrates a detailed block diagram of one embodiment of the functional steps for loading the CET data **508**. The first step is to read the CET data **1002** from the CET file. The second step, remove timeslice **1004**, includes removing any timeslice data if the any of the data in the timeslice is not numeric or is less than some specified value. In one embodiment, the specified value is 0.1. After any suspect data is removed **1004**, the next step is to determine if all CET files have been read **1008**. If not, the routine cycles back to the step of reading the CET data **1002**. If all the data files have been read **1008** and processed, the routine exits to the next step of calculating the CET averages **510**. In another embodiment, the CET data is converted to process units. For example, a voltage reading from a transmitter is converted to the process temperature value, such as degrees Celsius. This conversion step, in one embodiment, occurs after removing suspect timeslice data **1004**.

[0064] Figure 11 illustrates a detailed block diagram of one embodiment of the functional steps for calculating the CET averages **510**. The first step is to calculate an average for the timeslice **1102** for all the associated CETs. The next step is to calculate the deviations **1104**, which includes calculating the deviation from the average for each CET used in the average calculation. The next step is to evaluate the deviations to determine if all the CETs are to be used **1106**. This evaluation includes examining each deviation determined in step **1104** and if any CET has a deviation that is not above a specified low criteria and below a specified high criteria, that CET is removed as an outlier **1108** and the timeslice average is calculated **1102** again without considering that CET. If after calculating the deviations **1104**, all the CET deviations fall within limits, the next step is to calculate the standard deviation (SD) of the deviations **1110**. The standard deviation of the deviations for all the CETs used to calculate the average **1102** is determined for each timeslice.

[0065] Figure 12 illustrates a block diagram of one embodiment of the functional steps for selecting the data points **404**. The first step is to discard any outliers **1202**, that is, any data outside the start and end cursors. The selection **404** routine includes, in one embodiment, a user interface that displays the data obtained during the load data **402** step and allows the operator to select the data to be analyzed by bounding the desired data with graph cursors. In other embodiments, the selection **404** allows the operator to display and/or print the intermediate results obtained during the load data **402** routine.

[0066] The second step illustrated in Figure 12 is to calculate the three NR regions **1204**. Figure 13 illustrates a block diagram of one embodiment of the functional steps for calculating the three NR regions **1204**. The next step is to calculate one WR region **1206**. The lower temperature for the WR region equals the minimum WR leg average value. The upper temperature for the WR regions equals the minimum WR leg average value plus two times the WR region size. The WR region size is as specified in the configuration setup.

[0067] The next step illustrated in Figure 12 is to separate the RTD data into regions **1208**. Figure 14 illustrates a block diagram of one embodiment of the

functional steps for separating the RTD data into regions **1208**. The next step is to match the CET time to the remaining RTD data **1210** because the sample times must be the same for comparison.

[0068] Figure 13 illustrates a block diagram of one embodiment of the functional steps for calculating the three NR regions **1204**. The first step is to calculate the region 1 values **1302**. In one embodiment, the lower temperature equals the NR maximum temperature minus two times the NR region size. The upper temperature equals the NR maximum temperature. The NR maximum and the NR region size are as specified in the configuration setup.

[0069] The next step is to calculate the region 2 values **1304**. In one embodiment, the lower temperature equals the NR minimum plus the NR maximum temperature, divided by two, minus the NR region size. The upper temperature equals the NR minimum plus the NR maximum temperature, divided by two, plus the NR region size. The NR minimum and maximum temperatures and the NR region size are as specified in the configuration setup.

[0070] The next step is to calculate the region 3 values **1306**. In one embodiment, the lower temperature equals the NR minimum temperature. The upper temperature equals the NR minimum temperature plus two times the NR region size. The NR minimum and the NR region size are as specified in the configuration setup.

[0071] Figure 14 illustrates a block diagram of one embodiment of the functional steps for separating the RTD data into regions **1208**. The first three steps are to separate the NR region 1 data **1402**, separate the NR region 2 data **1404**, and separate the NR region 3 data **1406**. Each of these steps **1402**, **1404**, **1406** includes all timeslices where the NR average is within specified NR region. The final step is to separate the WR region data **1408**, which includes all timeslices where the WR average is within the WR region.

[0072] Figure 15 illustrates a block diagram of one embodiment of the functional steps for fluctuation removal, or removing deviate data, **406**. The first step is to calculate the average of the NR standard deviation (SD) **1502**. The result

is called the average NR fluctuation. The second step is to calculate the standard deviation (SD) around the average NR fluctuation **1504**. The result is called the NR fluctuation standard deviation (SDEV). The next step is a decision point whether to skip fluctuation removal **1506**. In one embodiment, this decision is determined by testing for the SDEV limit (multiplier) = 0. If not being skipped, then the next step is to reject the timeslices **1508** and then match the CET times **1510** to the RTD times. Rejecting the timeslice **1508** includes rejecting all timeslices where the NR standard deviation is not within the average NR fluctuation plus-or-minus the NR fluctuation standard deviation times the SDEV limit. If the fluctuation removal is to be skipped, then the next step is to match the CET times **1510** to the RTD times and not remove the deviation data. The SDEV limit is as specified in the configuration setup.

[0073] Figure 16 illustrates a block diagram of one embodiment of the functional steps for analyzing the data **408**. The first step is to calculate the RTD deviation in the three NR regions **1602**. Figure 17 illustrates a block diagram of one embodiment of the functional steps for calculating the RTD deviation in the three NR regions **1602**. The second step is to calculate the RTD deviation in the one WR region **1604**. Figure 18 illustrates a block diagram of one embodiment of the functional steps for calculating the RTD deviation in the one WR region **1604**. The next step is to calculate the average and standard deviation for the deviations of each RTD **1606**. Figure 19 illustrates a block diagram of one embodiment of the functional steps for calculating the average and standard deviation for the deviations of each RTD **1606**. The next step is to calculate the CET deviations in each region **1608**. Figure 20 illustrates a block diagram of one embodiment of the functional steps for calculating the CET deviations in each region **1608**. The final step illustrated in Figure 16 is to calculate the average for the deviations of each CET **1610**. Figure 21 illustrates a block diagram of one embodiment of the functional steps for calculating the average for the deviations of each CET **1610**.

[0074] Figure 17 illustrates a block diagram of one embodiment of the functional steps for calculating the RTD deviations in the three NR regions **1602**. The steps illustrated in Figure 17 are performed for each region and for each RTD. The first step is to subtract the NR average from the RTD value for each timeslice

1702. The results of this step are entered into a table of standard correction deviations **1704**. The next step is to subtract the appropriate NR hot or cold average from the RTD value for each timeslice **1706**. The results of this step are entered into a table of the hot/cold correction deviations **1708**. The next step is to subtract the appropriate NR loop average from the RTD value for each timeslice **1710**. The results of this step are entered into a table of the loop correction deviations **1712**. The next step is to subtract the appropriate NR hot or cold loop average from the RTD value for each timeslice **1714**. The results of this step are entered into a table of the hot/cold and loop correction deviations **1716**.

[0075] Figure 18 illustrates a block diagram of one embodiment of the functional steps for calculating the RTD deviation in the one WR region **1604**. The steps illustrated in Figure 18 are performed for each RTD. The first step is to determine whether the RTD is a NR RTD **1802**. If it is, the next step is to subtract the NR average from each RTD valued for each timeslice (zero) **1804**. The results of this step are entered into the tables for the standard correction deviations **1806**, the loop correction deviations **1808**, the hot/cold correction deviations **1810**, and the hot/cold and loop correction deviations **1812**. If the RTD is not an NR RTD, the next step is to subtract the WR average from each RTD for each timeslice **1820**. The results of this step are entered into a table of the standard correction deviations **1822**. The next step is to subtract the appropriate WR hot or cold average from each RTD for each timeslice **1824**. The results of this step are entered into a table of the hot/cold correction deviations **1826**. The next step is to subtract the appropriate WR loop average from each RTD for each timeslice **1828**. The results of this step are entered into a table of the loop correction deviations **1830**. The next step is to subtract the appropriate WR hot or cold loop average from each RTD for each timeslice **1832**. The results of this step are entered into a table of the hot/cold and loop correction deviations **1834**.

[0076] Figure 19 illustrates a block diagram of one embodiment of the functional steps for calculating the average deviation and the standard deviation for the deviations of each RTD **1606**. The steps illustrated in Figure 19 are performed for each RTD. The first step is to calculate the average and population standard deviation of the table of standard correction deviations **1902**. The next

step is to calculate the average and population standard deviation of the table of loop correction deviations **1904**. The next step is to calculate the average and population standard deviation of the table of hot/cold correction deviations **1906**. The next step is to calculate the average and population standard deviation of the table of hot/cold (both) and loop correction deviations **1908**.

[0077] Figure 20 illustrates a block diagram of one embodiment of the functional steps for calculating the CET deviations in each region **1608**. The first step is to determine if the data is in the NR region **2002**. If the data is in the NR region, the first step is to subtract the matched NR RTD average from the CET data **2004**. The results of this step produces the CET deviations from the NR average **2006**. The next step is to subtract the CET average from the CET data **2014**, thereby producing the CET deviations from the CET average **2016**. If the data is not in the NR region, the first step is to subtract the matched WR RTD average from the CET data **2010**. The results of this step produces the CET deviations from the WR average **2012**. The next step is to subtract the CET average from the CET data **2014**, thereby producing the CET deviations from the CET average **2016**.

[0078] Figure 21 illustrates a block diagram of one embodiment of the functional steps for calculating the average for the deviations of each CET **1610**. The steps illustrated in Figure 21 are performed for each CET. The first step is to calculate the average of deviations from NR average **2102**. The next step is to calculate the average of deviations from the CET average **2104**.

[0079] Figure 22 illustrates a block diagram of the functional steps for generating the RTD report **410**. The first step is to calculate the percent removed for the NR region **2202**. Figure 23 illustrates a block diagram of one embodiment of the functional steps for calculating the percent removed for the NR region **2202**. The next step is to calculate the percent removed for the WR region **2204**. Figure 24 illustrates a block diagram of one embodiment of the functional steps for calculating the percent removed for the WR region **2204**. The next step is to calculate the mean value of all averages **2206**. Figure 25 illustrates a block diagram of one embodiment of the functional steps for calculating the mean value of all averages **2206**. The next step is to select the correction method and

temperature region **2208**. The user chooses which temperature region and correction method to use for results. The final step illustrated in Figure 22 is to compare the RTD results with the limits **2210**.

[0080] Figure 23 illustrates a block diagram of one embodiment of the functional steps for calculating the percent removed for the NR region **2202**. The steps illustrated in Figure 23 are performed for each NR region and for each RTD. With respect to the calculations for percent removed identified for Figure 23, the percent removed for each RTD is calculated by dividing the number of samples exceeding the averaging criteria by the number of samples in the region.

[0081] The first step illustrated in Figure 23 is to determine whether the RTD is used in the NR average **2302**. If the RTD is used in the NR average, the next step is to calculate the percent removed from the NR average **2304** for the table of the standard correction deviations. If not, then the percent removed is not applicable for this RTD for the table of the standard correction deviations **2406**. The next step is to determine whether the RTD is used in the loop average **2312**. If the RTD is used in the loop average, the next step is to calculate the percent removed from the loop average **2314** for the table of the loop correction deviations. If not, then the percent removed is not applicable for this RTD for the table of the loop correction deviations **2416**. The next step is to determine whether the RTD is used in for the hot/cold average **2322**. If the RTD is used in the hot/cold average, the next step is to calculate the percent removed from the hot/cold average **2324** for the table of the hot/cold correction deviations. If not, then the percent removed is not applicable for this RTD for the table of the hot/cold correction deviations **2426**. The next step is to determine whether the RTD is used in the hot/cold or loop average **2332**. If the RTD is used in the loop average, the next step is to calculate the percent removed from the hot/cold or loop average **2334** for the table of the hot/cold or loop correction deviations. If not, then the percent removed is not applicable for this RTD for the table of the hot/cold or loop correction deviations **2436**.

[0082] Figure 24 illustrates a block diagram of one embodiment of the functional steps for calculating the percent removed for the WR region **2204**. The

steps illustrated in Figure 24 are performed for each WR region and for each RTD. With respect to the calculations for percent removed identified for Figure 24, the percent removed for each RTD is calculated by dividing the number of samples exceeding the averaging criteria by the number of samples in the region.

[0083] The first step illustrated in Figure 24 is to determine whether the RTD is used in the WR average **2402**. If the RTD is used in the WR average, the next step is to calculate the percent removed from the WR average **2404** for the table of the standard correction deviations. If not, then the percent removed is not applicable for this RTD for the table of the standard correction deviations **2406**. The next step is to determine whether the RTD is used in the loop average **2412**. If the RTD is used in the loop average, the next step is to calculate the percent removed from the loop average **2414** for the table of the loop correction deviations. If not, then the percent removed is not applicable for this RTD for the table of the loop correction deviations **2416**. The next step is to determine whether the RTD is used in for the hot/cold average **2422**. If the RTD is used in the hot/cold average, the next step is to calculate the percent removed from the hot/cold average **2424** for the table of the hot/cold correction deviations. If not, then the percent removed is not applicable for this RTD for the table of the hot/cold correction deviations **2426**. The next step is to determine whether the RTD is used in the hot/cold or loop average **2432**. If the RTD is used in the loop average, the next step is to calculate the percent removed from the hot/cold or loop average **2434** for the table of the hot/cold or loop correction deviations. If not, then the percent removed is not applicable for this RTD for the table of the hot/cold or loop correction deviations **2436**.

[0084] Figure 25 illustrates a block diagram of one embodiment of the functional steps for calculating the mean value of all averages **2206**. The steps illustrated in Figure 25 are performed for each region. The first step is to calculate the mean NR average **2502**. The next step is to calculate the mean NR loop averages **2504**, the mean NR hot and cold averages **2506**, and the mean NR hot and cold loop averages **2508**. The next step is to calculate the mean WR average **2510**, the mean WR loop averages **2512**, the mean WR hot and cold averages **2514**, and the mean WR hot and cold loop averages **2516**.

[0085] Figure 26 illustrates a block diagram of the functional steps for generating the CET report **412**. The first step is to calculate the percent of CET removed from the CET average for each CET **2602**. The next step is to calculate the CET quadrant averages **2604**. Figure 27 illustrates a block diagram of one embodiment of the functional steps for calculating the CET quadrant averages **2604**. The next step is to select the correction and region **2606**. The final step illustrated in Figure 26 is to compare the CET results with the limits **2608**.

[0086] Figure 27 illustrates a block diagram of one embodiment of the functional steps for calculating the CET quadrant averages **2604**. The first step is to calculate the average deviation of all CETs in the quadrant within the CET averaging criteria **2702**. Then, the deviations are added to the CET average for the region **2704**. This results in the CET quadrant average **2706**. The next step is to determine whether any quadrants remain **2708**. If there is another quadrant not yet calculated, then the process is repeated starting at the calculation step **2702**. If no quadrants remain to be averaged, the routine exits.

[0087] Figure 28 illustrates a block diagram of the functional steps for recalibrating any deviating RTDs **414**. Only deviating RTDs are recalibrated in accordance with the routine illustrated in Figure 28. The first step is to calculate a resistance versus temperature table **2802**. Figure 29 illustrates a block diagram of one embodiment of the functional steps for calculating a resistance versus temperature table **2802**. The next step is to calculate new coefficients **2804**. Figure 30 illustrates a block diagram of one embodiment of the functional steps for calculating new coefficients **2804**. The next step is to produce a recalibration-original calibration plot **2806**. Figure 36 illustrates a block diagram of one embodiment of the functional steps for producing a recalibration-original calibration plot **2806**. The next step is to calculate the recalibration uncertainty **2808**. Figure 37 illustrates a block diagram of one embodiment of the functional steps for calculating the recalibration uncertainty **2808**.

[0088] Figure 29 illustrates a block diagram of one embodiment of the functional steps for calculating a resistance versus temperature table **2802**. The first step is to convert the RTD temperature into a resistance value with the

original coefficients **2902**. The second step is to determine whether the RTD is in the NR region **2904**. If it is the NR region, the next step is to select NR and average uncertainty values **2906**. If not, then the next step is to select WR average and uncertainty values **2908**. The results of these two steps **2906**, **2908** leads to the next step, which is to determine if all the regions have been processed **2910**. If not, the routine is repeated starting at the conversion step **2902**.

[0089] Figure 30 illustrates a block diagram of one embodiment of the functional steps for calculating new coefficients **2804**. The first step is to determine whether quadratic coefficients are to be calculated **3002**. If so, the next step is to calculate quadratic coefficients **3004**. Figure 31 illustrates a block diagram of one embodiment of the functional steps for calculating quadratic coefficients **3004**. If quadratic coefficients are not to be calculated, the next step is to determine if Callendar coefficients are to be calculated **3006**. If so, the next step is to calculate Callendar coefficients **3008**. Figure 32 illustrates a block diagram of one embodiment of the functional steps for calculating Callendar coefficients **3008**. If Callendar coefficients are not to be calculated, the next step is to determine if quadratic linear coefficients are to be calculated **3010**. If so, the next step is to calculate quadratic linear coefficients **3012**. Figure 33 illustrates a block diagram of one embodiment of the functional steps for calculating quadratic linear coefficients **3012**. If quadratic linear coefficients are not to be calculated, the next step is to determine if Callendar linear coefficients are to be calculated **3014**. If so, the next step is to calculate Callendar linear coefficients **3016**. Figure 34 illustrates a block diagram of one embodiment of the functional steps for calculating Callendar linear coefficients **3016**. If Callendar linear coefficients are not to be calculated, the next step is to calculate Westinghouse reference coefficients **3018**. Figure 35 illustrates a block diagram of one embodiment of the functional steps for calculating Westinghouse reference coefficients **3018**.

[0090] Figure 31 illustrates a block diagram of one embodiment of the functional steps for calculating quadratic coefficients **3004**. The first step is to determine if the data is in degrees Celsius **3102**. If not, then the data is converted to degrees Celsius **3104**. If the data is already in degrees Celsius, then the conversion step **3104** is skipped. The next step is to calculate the second order

polynomial least square fit (LSF) **3106** to determine the coefficients **3108**. The coefficients are R_0, A, and B for the quadratic equation.

[0091] Figure 32 illustrates a block diagram of one embodiment of the functional steps for calculating Callendar coefficients **3008**. The first step is to determine if the data is in degrees Celsius **3202**. If not, then the data is converted to degrees Celsius **3204**. If the data is already in degrees Celsius, then the conversion step **3204** is skipped. The next step is to calculate the second order polynomial least square fit (LSF) **3206** and convert the coefficients to Callendar coefficients **3208**. The final illustrated step is to determine the coefficients **3210**. The coefficients are R_0, α, and δ for the Callendar equation.

[0092] Figure 33 illustrates a block diagram of one embodiment of the functional steps for calculating quadratic linear coefficients **3012**. The first step is to determine if the data is in degrees Celsius **3302**. If not, then the data is converted to degrees Celsius **3304**. If the data is already in degrees Celsius, then the conversion step **3304** is skipped. The next step is to convert the temperature with the original coefficients to resistance R_T **3306**. The next step is to subtract R_T from the measured resistance to determine ΔR (delta resistance) **3308**. The next step is to calculate the linear least square fit (LSF) to temperature and ΔR **3310**. Then, the Δ (delta) offset and the Δ slope are added to the original coefficients **3312** to calculate the coefficients **3314**. The coefficients are R_0, A, and B for the quadratic linear equation.

[0093] Figure 34 illustrates a block diagram of one embodiment of the functional steps for calculating Callendar linear coefficients **3016**. The first step is to determine if the data is in degrees Celsius **3402**. If not, then the data is converted to degrees Celsius **3404**. If the data is already in degrees Celsius, then the conversion step **3404** is skipped. The next step is to convert the temperature with the original coefficients to resistance R_T **3406**. The next step is to subtract R_T from the measured resistance to determine ΔR (delta resistance) **3308**. The next step is to calculate the linear least square fit (LSF) to temperature and ΔR **3310**. Then, the Δ (delta) offset and the Δ slope are added to the original coefficients **3312**. The next step is to convert the coefficients to Callendar coefficients **3314**.

The final illustrated step is to determine the coefficients **3316**. The coefficients are R_0, α, and δ for the Callendar linear equation.

[0094] Figure 35 illustrates a block diagram of one embodiment of the functional steps for calculating Westinghouse reference coefficients **3018**. The first step is to determine if the data is in degrees Celsius **3502**. If not, then the data is converted to degrees Celsius **3504**. If the data is already in degrees Celsius, then the conversion step **3504** is skipped. The next step is to convert the temperature to resistance by using a reference function R_W **3506**. The reference function R_W is a function based on calculating coefficients as promulgated by Westinghouse Corporation. The next step is to subtract R_W from the measured resistance to determine ΔR (delta resistance) **3508**. The next step is to calculate the linear least square fit (LSF) to temperature and ΔR **3510**. Then, the Δ (delta) offset and the Δ slope are converted to the Westinghouse reference slope and offset **3512** to calculate the coefficients **3514**. The coefficients are slope and offset for the Westinghouse reference equation.

[0095] Figure 36 illustrates a block diagram of one embodiment of the functional steps for producing a recalibration minus original calibration plot for a deviating RTD **2806**. The steps of Figure 36 provide a comparison of out of tolerance instrument measurements to the average measurements. Figure 38 illustrates an example screen shot showing an RTD calibration plot **3808** of new calibration values minus original calibration values versus temperature. The first step shown on Figure 36 is to calculate the resistance with the original equation and coefficients for the RTD **3602**. The next step is to calculate a new temperature with new calibration coefficients **3604**. The next step is to subtract the original temperature from the new temperature **3606**. The next step is to calculate the resistance with the original equation **3608**. The next step is to calculate the original temperature from the recalibration resistance data **3610**. The next step is to subtract the original recalibration temperature from the recalibration temperature data **3612**. The final illustrated step is to plot the recalibration data versus the original data **3614**.

[0096] The first three steps **3602**, **3604**, **3606** illustrated in Figure 36 calculate a curve **3812** (illustrated in Figure 38) determined from subtracting the original calibration values from the recalibration values. This curve **3812** is shown in relation to an abscissa **3814** at zero. The first step **3602** determines the resistance value corresponding to the measured temperature, using the original coefficients with the equation to calculate the temperature from a resistance. The calculated resistance is the actual resistance corresponding to the temperature as measured by the instrument. The second step **3604** calculates a new temperature based on the actual resistance determined in the previous step **3602** and the equation with the new coefficients. The third step **3606** determines the difference between the temperature as measured and the new temperature (the temperature as calculated). These differences define the curve **3812**.

[0097] Steps four through six **3608**, **3610**, **3612** illustrated in Figure 36 calculate specific points **3822**, **3824**, **3826** on the previously determined curve **3812** shown on Figure 38. These three steps **3608**, **3610**, **3612** are somewhat similar to the first three steps **3602**, **3604**, **3606**; however, they are applied to the individual data points for the out of tolerance instrument. The fourth step **3608** determines the resistance corresponding to the temperature using the equation with the original coefficients. This calculation is performed for the out of tolerance instrument at a specified point. The fifth step **3610** determines a calculated temperature from the recalibration resistance data. The sixth step **3612** determines the difference between the original temperature value and the recalibration temperature data. In another embodiment, the temperature of the out of tolerance instrument is retrieved from the data file or another stored variable instead of recalculating the temperature.

[0098] The final step **3614** illustrated in Figure 36 produces the results of the previous calculations. The results, in various embodiments, is a display, a printout, a chart, a plot, or other depiction of the calculation results made available to the operator. On embodiment of the results are illustrated in Figure 38.

[0099] Figure 38 illustrates an example screen shot of RTD calibration information. The information is shown in four regions: one region identifies the instrument **3802**, the second shows the recalibration data **3804**, the third shows the quadratic equation calibration coefficients **3806** for the instrument, and the fourth region shows an RTD calibration plot **3808**. The recalibration data **3804** includes the temperature and the corresponding resistance and uncertainty for the instrument.

[00100] Figure 37 illustrates a block diagram of one embodiment of the functional steps for calculating the recalibration uncertainty for a deviating RTD **2808**. Figure 39 illustrates one example of a plot of calibration uncertainty versus temperature. The first step shown in Figure 37 is to subtract the uncertainty from the temperature for the RTD **3702**. The next step is to calculate new coefficients based on the calibration type **3704**. The next step is to subtract the original coefficients from the new coefficients **3706**. The next step is to determine whether all the permutations have been calculated **3708**. These permutations include every combination of uncertainties for the data points. If not, then the next step is to add the uncertainty to the next combination **3710** and then repeat calculating new coefficients **3704**. If all permutations have been calculated, the next step is to calculate the maximum and minimum deviation for each temperature **3712**. The maximum and minimum deviation identifies the bounds for each temperature. The final step **3714** illustrated in Figure 37 produces the results of the previous calculations. The results, in various embodiments, is a display, a printout, a chart, a plot, or other depiction of the calculation results made available to the operator. On embodiment of the results are illustrated in Figure 39.

[00101] Figure 39 illustrates an example screen shot of RTD calibration uncertainty information. The information is shown in four regions: one region identifies the instrument **3902**, the second shows the recalibration data **3904**, and the third region shows an RTD calibration uncertainty plot **3906**. The recalibration data **3904** includes the temperature and the corresponding resistance and uncertainty for the instrument.

[00102] Referring to the RTD calibration uncertainty plot **3906** on Figure 39, for each of the temperature points **3912**, **3914**, **3916**, there is an associated uncertainty, plus **3922A**, **3924A**, **3926A** and minus **3922B**, **3924B**, **3926B**. A set of curves **3930A-F** are fit to each combination of uncertainty applied to the data points **3912**, **3914**, **3916**. The set of curves **3930A-F** are useful for extrapolating the range of uncertainty for data points outside the region bounded by the known or measured **3912**, **3914**, **3916**. For example, in one embodiment, the known data points are taken within a narrow operating range. The limits on the process are either above or below normal operating ranges. By extrapolating the calibration curves with uncertainty, the limits can be evaluated to determine whether they should be adjusted to account for the extrapolated curves **3930A-F**.

[00103] Figure 40 illustrates one embodiment of a screen shot of an RTD calibration table. The information is shown in three regions: one region identifies the instrument **4002**, the second shows the calibration constants, or coefficients, **4004**, and the third region shows the calibration resistance for a range of temperatures **4006**.

[00104] In one embodiment, each of the functions identified in Figures 3 to 37 are performed by one or more software routines run by the cross calibration processor **126**. In another embodiment, one or more of the functions identified are performed by hardware and the remainder of the functions are performed by one or more software routines run by the processor **126**.

[00105] The cross calibration processor **126** executes software, or routines, for performing various functions. These routines can be discrete units of code or interrelated among themselves. Those skilled in the art will recognize that the various functions can be implemented as individual routines, or code snippets, or in various groupings without departing from the spirit and scope of the present invention. As used herein, software and routines are synonymous. However, in general, a routine refers to code that performs a specified function, whereas software is a more general term that may include more than one routine or perform more than one function. Those skilled in the art will recognize that it is possible to

program a general-purpose computer or a specialized device to implement the invention.

[00106] The automated system for cross calibration includes several functions, both hardware and software. The system includes a function for communicating with a plant monitoring system. In one embodiment, the function of communicating is performed via a network connection between the cross calibration processor **126** and the plant monitoring system **240**. The system includes a function for processing, which, in one embodiment, is performed by the cross calibration processor **126**.

[00107] The system includes a function for performing a cross calibration of plant instruments. In one embodiment, the function of cross calibration is performed by retrieving data **302** from the plant monitoring system **240**, determining the average temperatures **306** of the various temperature instruments, determining if there are any deviations **308** from the averages, and for deviations outside a range **310**, determining new coefficients, or calibration curves, **312**. For those instruments with no deviations, there is no change **314**. In another embodiment, the data sorted **304** after it is retrieved **302**. In still another embodiment, the data is loaded **402**, data points are selected **404**, fluctuation data is removed **406**, and the data is analyzed **408**. In another embodiment, after the data is analyzed **408**, deviating or outlying RTDs are recalibrated **414**. In yet another embodiment, after the data is analyzed **408**, an RTD report **410** and/or a CET report **412** is made available.

[00108] The system includes a function for recalibrating a deviating instrument. In one embodiment, the function of recalibrating is performed by the step of recalibrating the RTD **414**, as executed by the cross calibration processor **126**. In another embodiment, the function of recalibrating is performed by the cross calibration processor **126** executing the steps of calculating the resistance value versus temperature **2802**, calculating new coefficients **2804**. In another embodiment, the function of recalibrating is performed by additionally producing a recalibration minus calibration plot **2806**. In still another embodiment, the

function of recalibrating is performed by additionally calculating recalibration uncertainty **2808**.

[00109] From the foregoing description, it will be recognized by those skilled in the art that methods and apparatus for an automated system for cross calibration has been provided. The automated system includes a processor **126** in communication with a plant computer **122** and plant data storage unit **124** or a plant monitoring system **240**. The processor **126** extracts operating data for a collection of instruments **104** and performs a cross-calibration using that data.

[00110] While the present invention has been illustrated by description of several embodiments and while the illustrative embodiments have been described in considerable detail, it is not the intention of the applicant to restrict or in any way limit the scope of the appended claims to such detail. Additional advantages and modifications will readily appear to those skilled in the art. The invention in its broader aspects is therefore not limited to the specific details, representative apparatus and methods, and illustrative examples shown and described. Accordingly, departures may be made from such details without departing from the spirit or scope of applicant's general inventive concept.